Protecting Night Skies and Naturally Dark Conditions in National Parks

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Visual Resource Stewardship Conference:

Landscape and Seascape Management in a Time of Change

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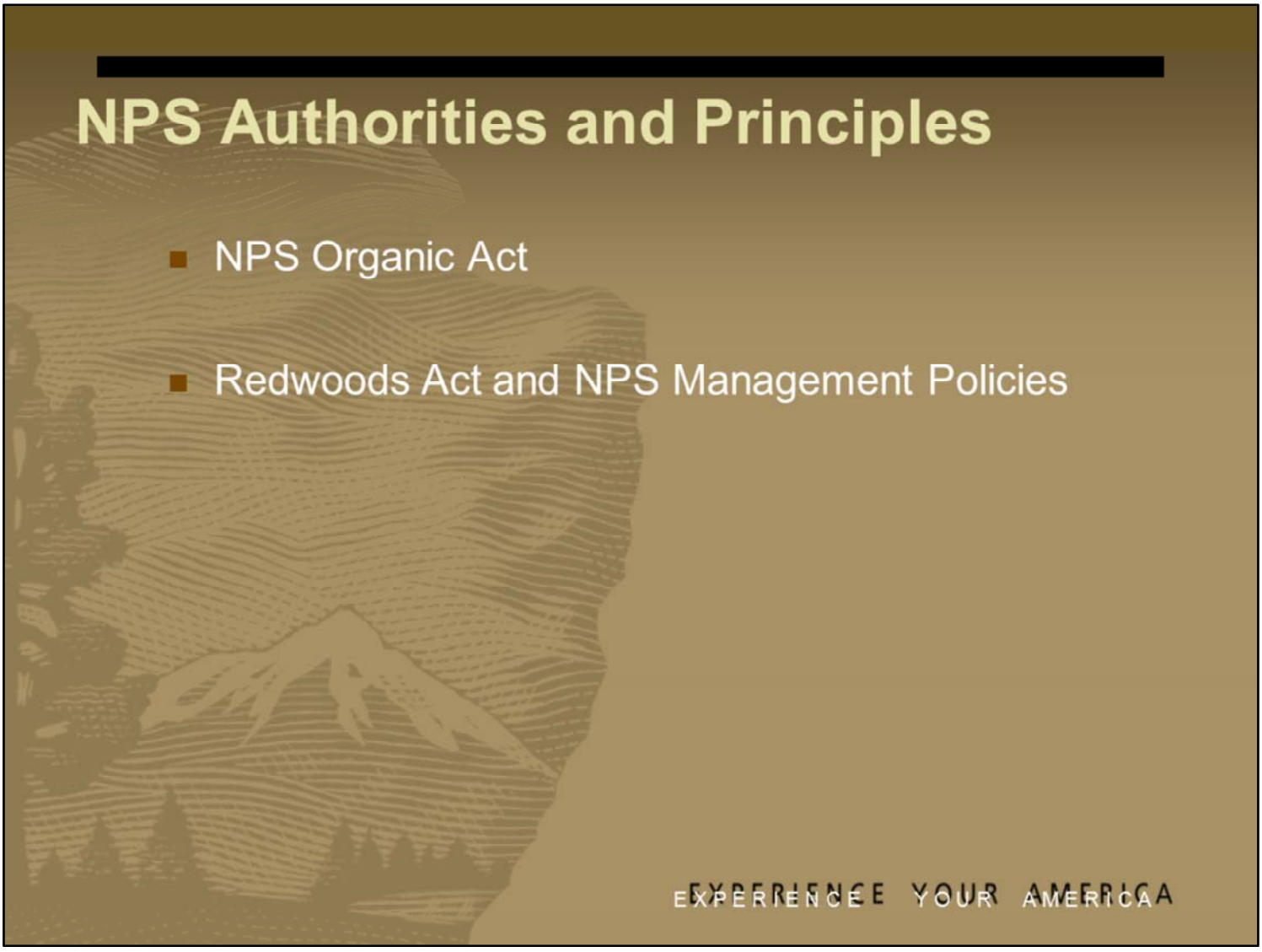
There are five key points that I'd like to cover in today's presentation..

So let's jump right in to a little introduction about the NPS policies and authorities for protecting night skies and the natural cycles of light and dark.



The overarching mission and mandate of the NPS is provided in the NPS Organic Act that established the agency. The Organic Act states that NPS will conserve natural and cultural resources and values under our protection while also providing for the enjoyment of those resources and values. And we are to manage them in a way that will leave them unimpaired for future generations

Subsequent legislation and NPS Policy states that "when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act"

"*to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*"

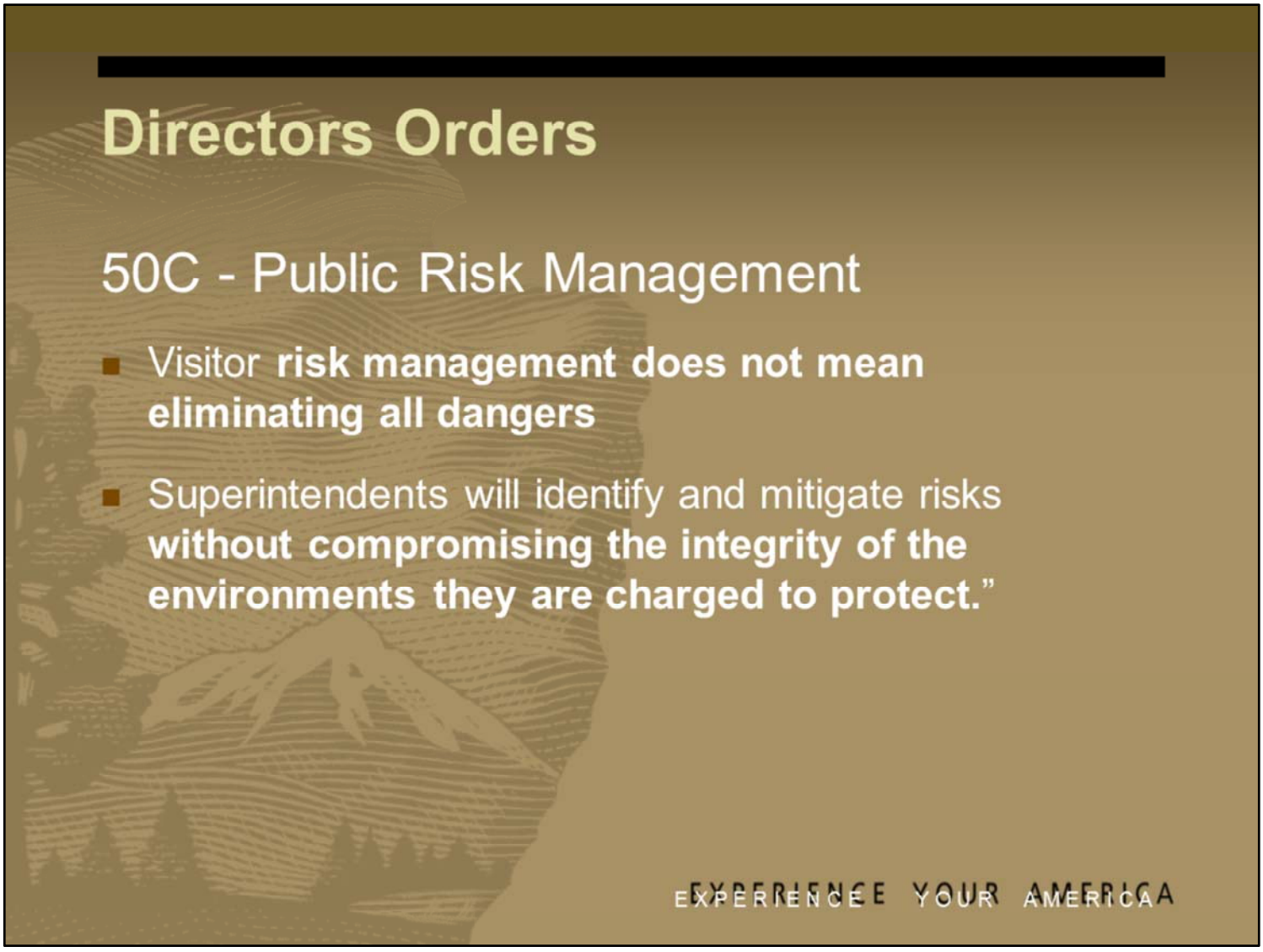
NPS Management Policies is an high level policy document that describes the NPS position on a wide range of issues facing the agency. Management policies contains a policy related to Lightscape Management. The policy states that NPS will

- Preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light.
- minimize light that emanates from park facilities, to prevent the loss of dark conditions and of natural night skies,
- …Because we also understand that light that affects the photic environment of parks often originates outside of park boundaries, we and will also seek the cooperation of park visitors, neighbors, and local government agencies to prevent or minimize the intrusion of artificial light into park environments and ecosystems.

The Management Policy on light also

- Restricts the use of artificial lighting in parks to those areas where security, basic human safety, and specific cultural resource requirements must be met. That's an important statement. It basically states that there must be a reason that meets those requirements in order for light an area.
- Requires NPS to use minimal-impact lighting techniques;
- Shield lighting where necessary to prevent the disruption of the night sky, natural cave processes, physiological processes of living organisms, and similar natural processes

The policy also recognizes that there are some areas and situations where light should not be introduced into the environment. It states that the NPS will not use artificial lighting in areas such as sea turtle nesting locations where the presence of the artificial lighting will disrupt park resources and values.



Next I want to briefly discuss an NPS policy that is closely related to protection of night skies and dark environments…Public safety. This is important because visitor safety is often cited as the reason for installing lighting in parks. NPS has a Director's Order on public risk management. The DO states that "Within the context of the Organic Act, visitor **risk management does not mean eliminating all dangers**, nor can the NPS guarantee visitor safety or be responsible for acts and decisions made by visitors that may result in their injury or illness

It also states that Park superintendents will seek to identify risks within their jurisdiction and to mitigate these risks **without compromising the integrity of the environments they are charged to protect.**"

Specifically, it states that Lighting, and other safety measures might be appropriate in some settings while not in backcountry campsites, trails, and similar pristine settings, or even in some urban locations.

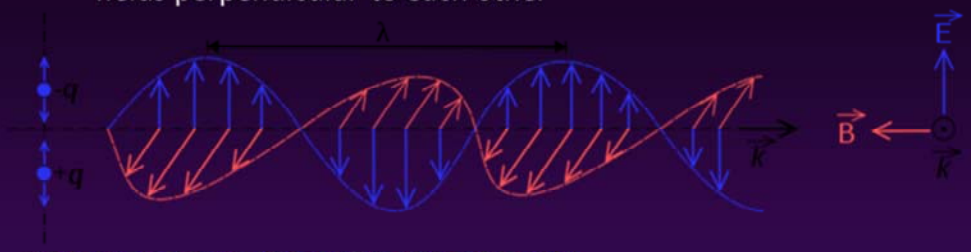
As you can see NPS policy requires us to protect night skies and dark environments and provide direction on how superintendents and park managers should consider tradeoffs between protecting the lightscape and providing for basic human safety.

Next we want to provide a bit of background on light and light pollution. I want to focus on the key concepts that help us measure and manage the photic environment of parks.

What is light?

ELECTROMAGNETIC WAVE THEORY (Maxwell)

describes visible light as an oscillating wave of electric and magnetic fields perpendicular to each other

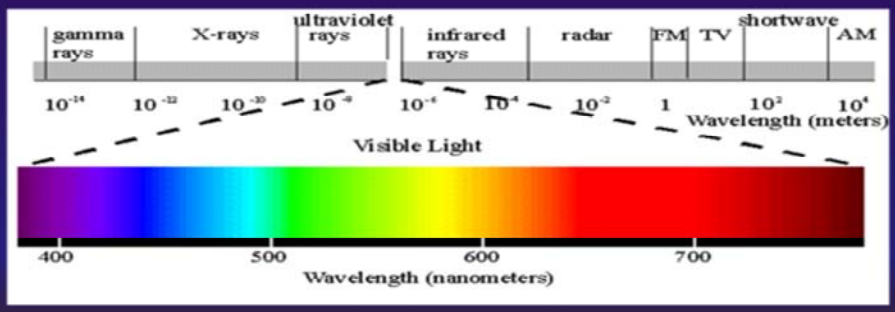


THE ELECTROMAGNETIC SPECTRUM

Includes a range of photon energy levels, from the highest (gamma rays) to the lowest (radio waves)

VISIBLE LIGHT

Includes a narrow band of this spectrum, corresponding to the peak of the sun's spectral output



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What is this thing called light? Many dissertations have been written and a few Nobel prizes have probably addressed this question. So my definition is likely going to seem a little superficial in comparison. But light can be explained by the electromagnetic wave theory developed by Maxwell in the late 1800s. He described visible light as …

(see figure above)

I think it helps to think of light as just a portion of the electromagnetic spectrum that ranges in energy level from Gamma rays to radio waves. Light is just a narrow portion of that spectrum that stimulates nerve receptors in our eyes and allows us to sense our environment.

1.1 What is light?

THE BLACK BODY CURVE (Wein's Displacement Law)

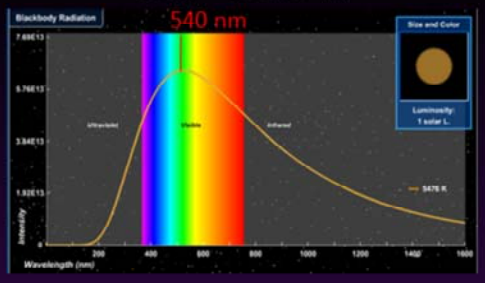
Predicts the peak wavelength of a star's spectrum based upon the star's surface temperature

The human eye is sensitive to the region of peak intensity in the sun's spectrum, obviously not by mere chance

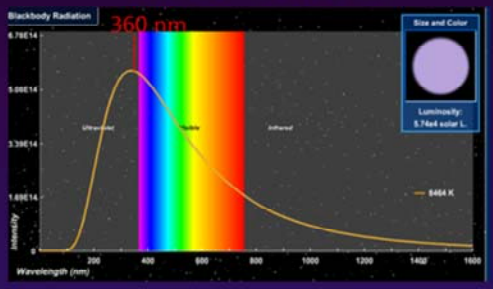
WHITE LIGHT

Is a mixture of the colors of the sun's spectrum as perceived by the human eye

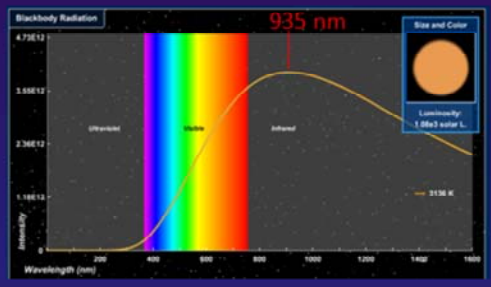
Sun 5300° K



Deneb 8100° K



Antares 3100° K



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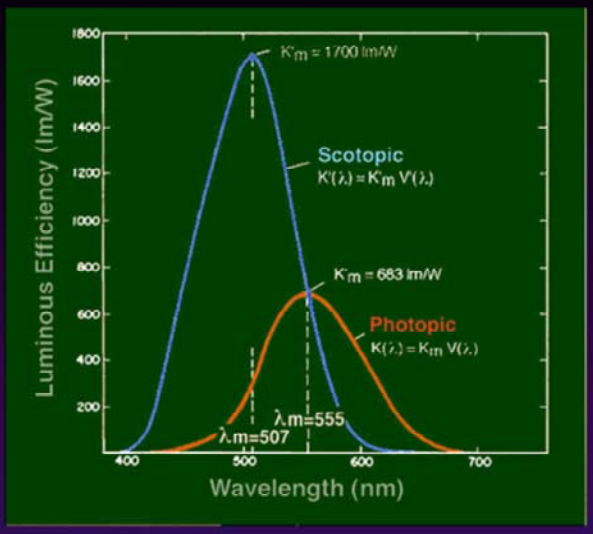
The point of this slide is to illustrate the relationship between the "color" of light and temperature. Predicts the peak wavelength of a star's spectrum based upon the its surface temperature. Basically stars vary in color, some appear blue, some red, other yellow and that difference is based on its temperature. Why is this important? This is why the spectra –or color – of a light bulb is typically expressed in degrees Kelvin.

SPECTRAL SENSITIVITY OF THE HUMAN EYE

Varies under different light levels.

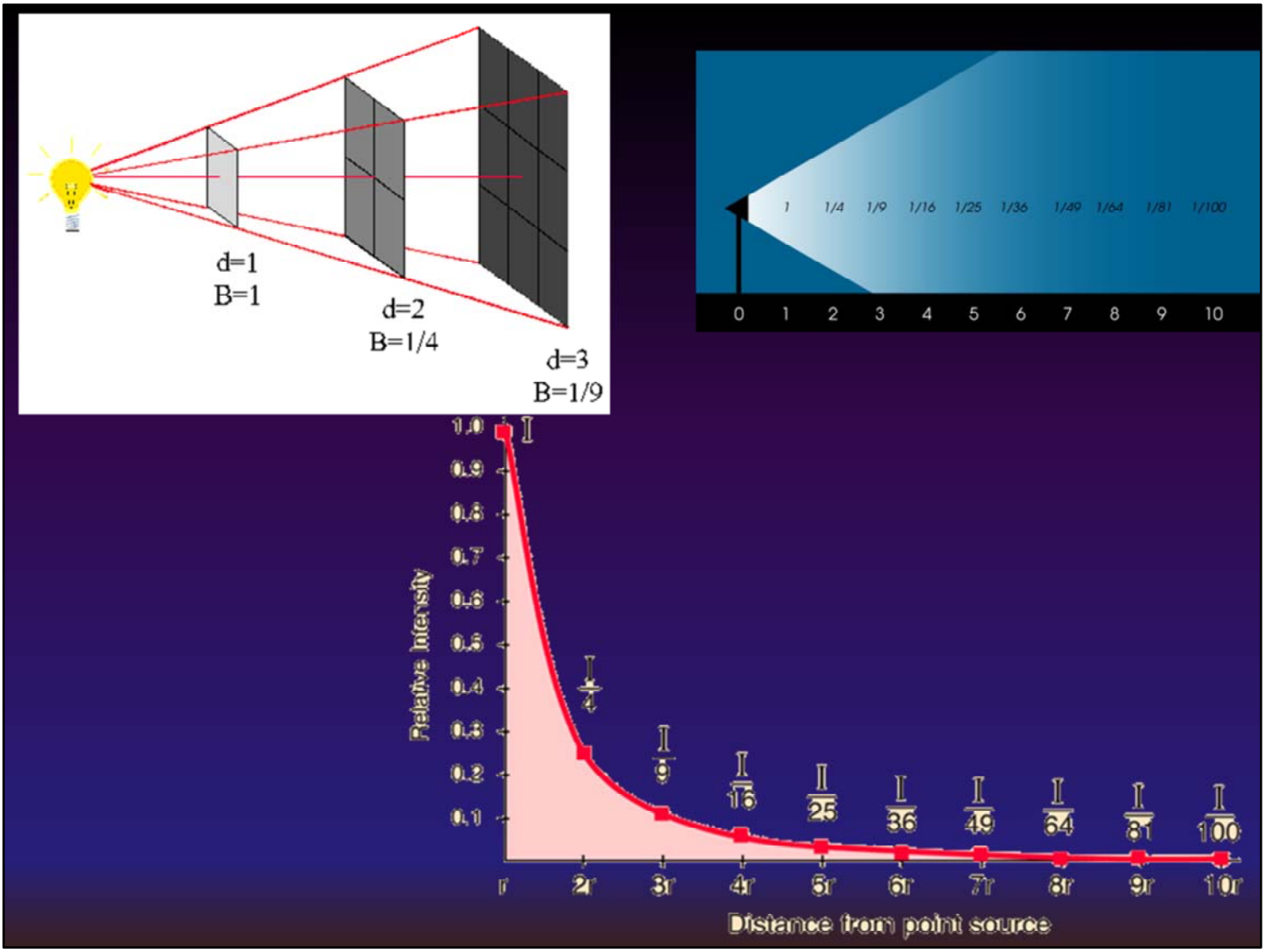
The eye is nearly three times as sensitive in scotopic (or so-called "dark adapted") as it is in photopic (normal) state,



Under scotopic vision the wavelength of peak sensitivity is shifted toward the blue part of the spectrum, from 555 nm to 507 nm.

The transition between the two states is not abrupt, but a continuum, termed *mesopic*. Mesopic vision is experienced in the natural environment under moonlight or twilight.

The human eye has a a wide range of sensitivities. The eye see well in full daylight, but also is able to pick out details in the landscape on moonless nights. Go to slide



Next I want to discuss how light diminishes as a function of Distance. The intensity of light diminishes based on the inverse square law. This is an important concept for understanding impacts AND mitigation strategies. When you double the distance between a light and a receptor, the light is ¼ as bright. When you move closer by half you increase the brightness by a factor of 4.

Light Tresspass

LIGHT TRESPASS

Is light directly striking the observer from an anthropogenic source. This type of light pollution illuminates the observer and the landscape unnaturally.

Above: light trespass as seen by an observer on Highway 190 in Death Valley.

Right: the desert landscape illuminated by these lights.

Affects environment through Sky Glow and Glare

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LIGHT TRESPASS Is light that striking the observer from a human source. There are two main types of light trespass that can affect natural and cultural resources Sky Glow and Glare

SKY GLOW

Is light scattered and reflected off of air molecules and atmospheric aerosols. The observer sees anthropogenic light originating on the ground in the sky. The sky appears luminous.

This type of light pollution damages the aesthetics of the night sky, *and* illuminates the observer and the landscape unnaturally.

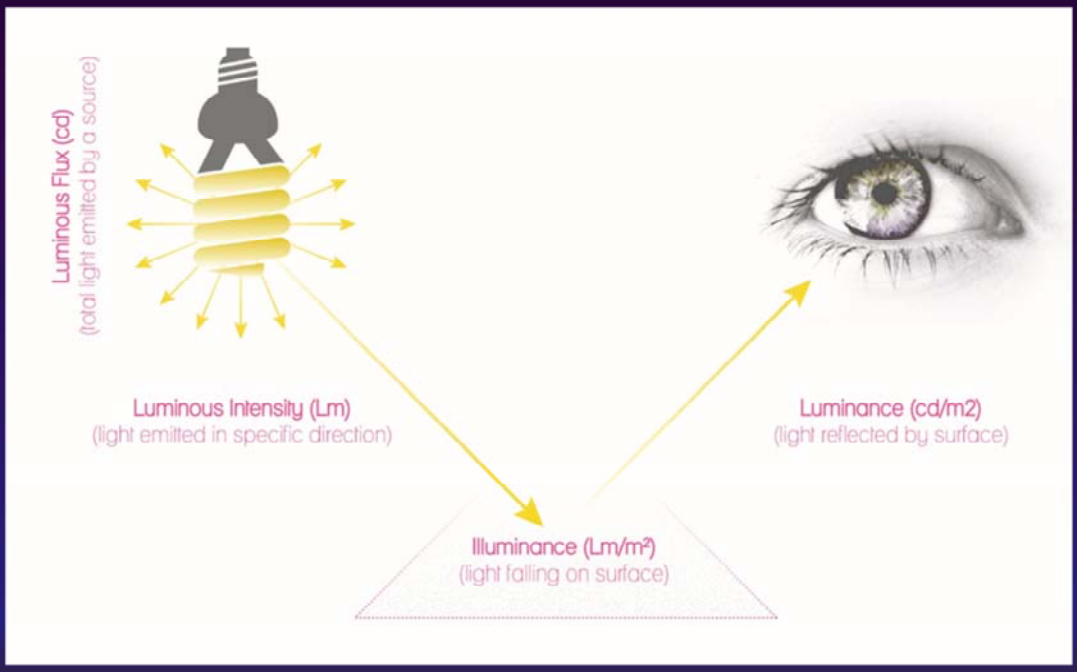
Glare is the other form of light trespass that can affect visual resources in addition to visitors and natural and cultural resources.

It is the light that strikes your eye directly from a source. Glare degrades the visual scene in two ways. First it obscures visual information and second it can destroy your scotopic or dark adapted vision. Your eyes will automatically adjust to the brightest source of light in a scene, So when your eye sees a source of glare like the light in the photo, you really can't see anything in the vicinity of the light. If there was a person (or a threat) near that light, they would be invisible. Light is a tool for extracting information from your environment, and improper lighting often does the opposite. That's why adding light to a scene doesn't always increase safety and security.

Improper lighting (glare) also creates shadows that can obscure information. So for safety and security it's not necessarily how much light you have on a scene, it's a function of how effectively the light provides information about your surroundings

ILLUMINANCE AND LUMINANCE

Are measures of light from the whole field of view of the observer. Both are produced by spilled light from outdoor fixtures, and both can be calibrated to known standards.



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Illuminance and Luminance are two additional concepts That are important for understanding light.

Illuminance is a measure of luminous flux on a surface of a given area, or luminous flux density. It is what matters most when the human eye is trying to examine objects by reflected light. Illuminance is a very useful measure in quantification of anthropogenic light in the natural environment. Measured in lux. Footcandle is the British unit equivalent and equals 0.093 lux or about 1/10 lux.

Illuminance from the sky or a light source overhead is often measured with the detector in a horizontal plane. We call this measure horizontal illuminance. Horizontal illuminance is a good measure of sky brightness near the zenith or illuminance from a pole mounted outdoor light.

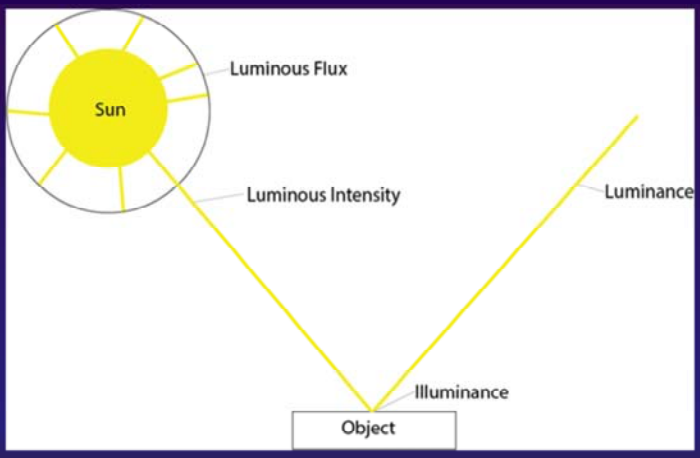
Illuminance from a light source at a distance on the horizon (or from the sky facing a certain direction) may be measured with the detector in a vertical plane. We call this measure vertical illuminance. Vertical illuminance is an excellent measure of light trespass.

LUMINANCE

Is Luminous Intensity per unit area (candela/m^2). It is sometimes called "perceived brightness", or "surface brightness" of an extended area.

Changing the characteristics of a surface can increase or decrease it's luminance

- Texture
- Color
- Reflectivity



See slide

Light in the Natural Night Landscape

Horizontal, Vertical, and Hemispheric Illuminance exists from the night sky, allowing humans to navigate open landscapes. The luminance of the sky background may also be measured in high resolution. The light levels are small, so the units are milli- or 10^{-3} (millicandela/m^2, millilux).

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John Muir Trail Kings Canyon. Here are some benchmarks for luminance and illuminance levels under the full moon.

Measurement of Anthropogenic Light in the Landscape

Measuring anthropogenic light involves both illuminance and luminance measures. Often, it is most illustrative to express these values as a ratio to natural conditions. The two most important targets are sky glow and light trespass.

Sky glow (luminance)

Center of bright light dome
Luminance = 10-100 mcd/m²

Light trespass (illuminance)

Unshielded streetlamps
Illuminance = 0.5-50 mlux

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Both Luminance and Illuminance are important measures for understanding and measuring light pollution.

Luminance = sky glow

Illuminance = glare

Effects of stray light

Aesthetic/Astro-Tourism
Cultural
Ecological
Health
Wilderness

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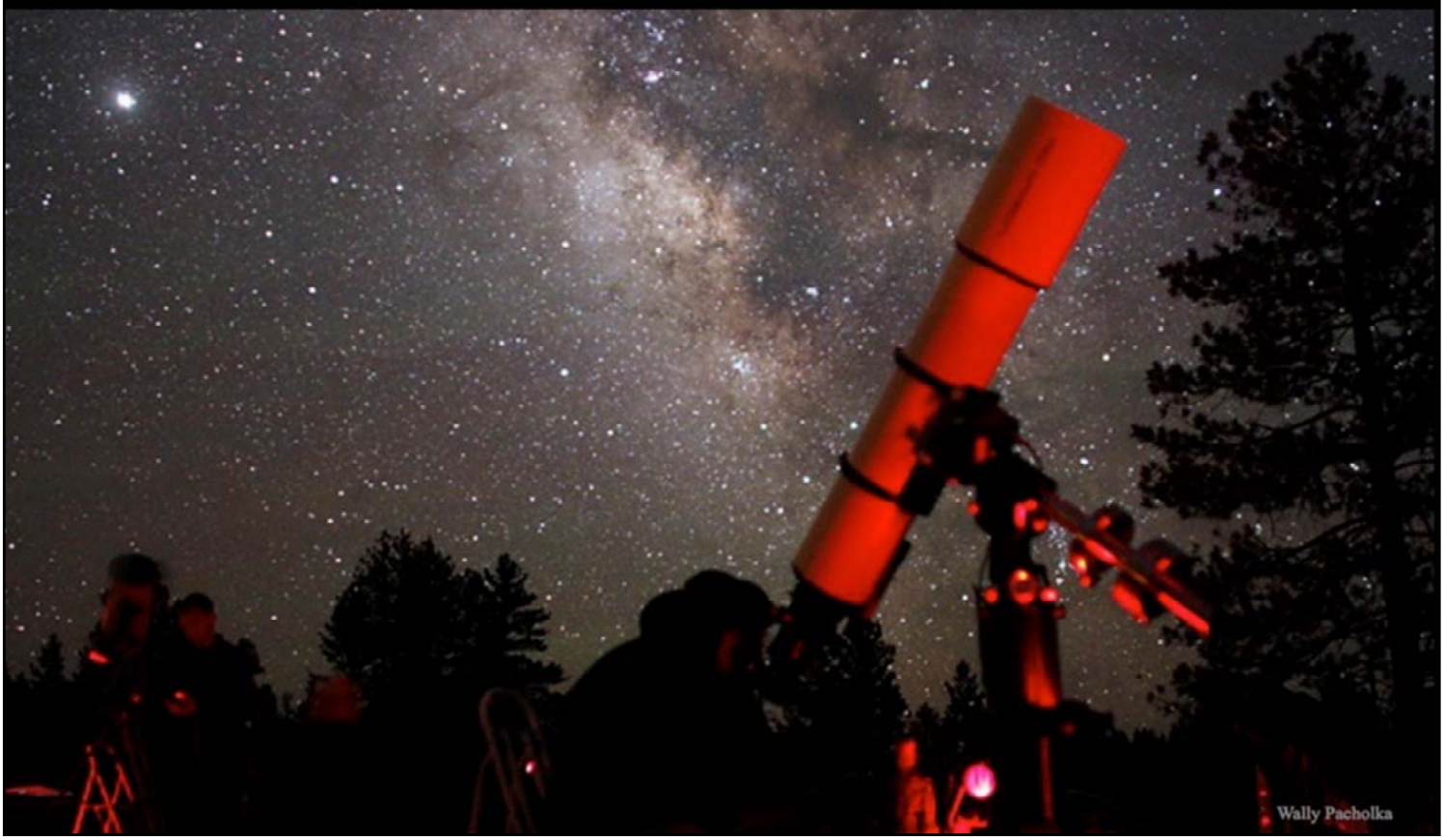
As the public loses the view of the night sky in their backyards, they are increasingly seeking it out in parks and protected lands. In many national parks, night time programs such as stargazing and moonlight hikes are among the most popular ranger-led activities.

Visitors (Bryce Canyon Astronomy Festival)



A visitor survey at two Utah parks revealed that 99% prefer to stargaze in a national park over other locations. 90% believed that there should be places that protect dark skies, 80% thought that the surrounding communities should help support such protection, and over 80 % indicated that the quality of night skies was an important or very important part of their visit.

Stargazing also has an economic benefit for gateway communities, as attending a stargazing program often turns a drive-thru park visit into additional dinner, breakfast, and lodging revenue for the local economy.

Sites such as the pyramids in Egypt, Stonehenge, Angkor Watt, Chichen Itza, and the pueblos of Chaco Canyon are standing testament to our relationship with the stars. Humans have looked to the night sky for direction and time, studied the motions of the stars and aligned our buildings to it. In this way the night sky connects us with our ancestral past.

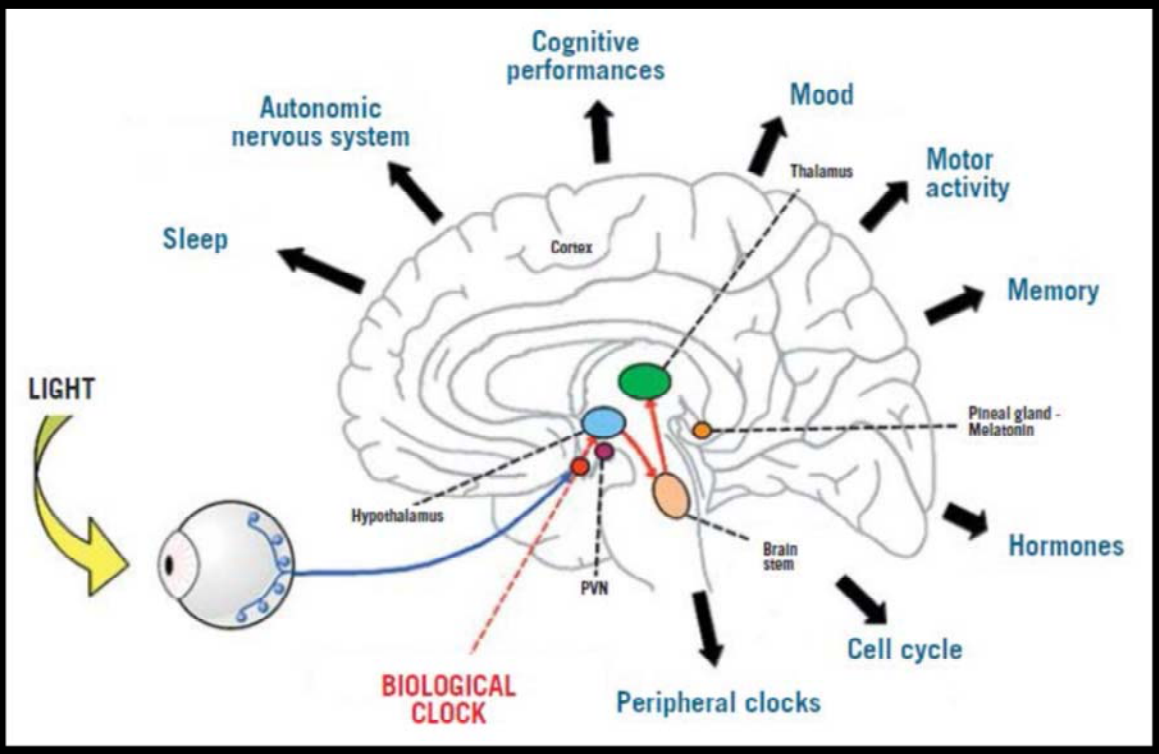
The next picture is of a Pawnee star chart. Part of the Pawnee creation myth says that Mars, mated with Venus, to produce the first humans. The Pawnee, place cultural and spiritual significance on the Pleiades cluster. The North star was considered to be a chief protecting the stars and the people, which makes sense because the north star is always up and everything else in the sky revolves around it.

Big Horn Medicine Wheel. It has a diameter of 90 feet, with 28 spokes that radiate outward and apparently stand for the number of days in a month. The medicine wheel marks both the rising and setting sun on the summer solstice. Other stones in the arrangement mark the rising of the bright stars Aldebaran, Rigel, and Sirius.
It serves as inspiration for countless works of art, literature, and music.

Since the beginning of life on this planet, there has always been a 28 or 29 day lunar cycle and a 24 hour daily cycle. This natural pattern is ingrained in the DNA of most creatures on Earth. Throughout this time the the environment has changed in countless ways.

Continents have formed and eroded, the sea level has risen and fallen, even the chemistry of our atmosphere has changed; but we have always had the same light-dark cycle - until the last hundred years.

Biological functions controlled by circadian rhythms



Claude Gronifer. Points de Vue, International Review of Ophthalmic Optics, N68, Spring, 2013

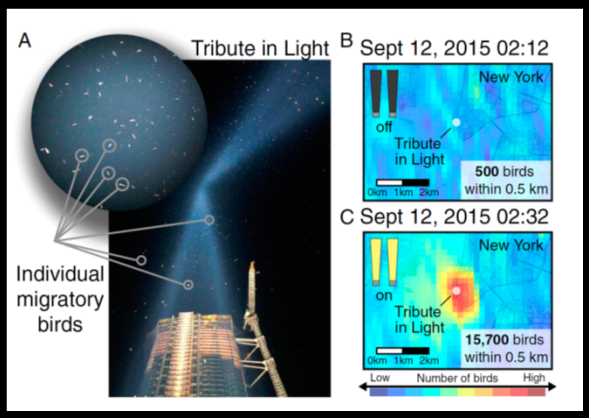
Night Skies: Ecological Consequences

Turtle hatchlings move toward bright areas. Passerine and many small birds migrate at night.

Many amphibians can detect light levels 100x dimmer than a human can. For many species, we are realizing that in addition to food, shelter, water, and space, they also require darkness.

Night Skies: Ecological Consequences

- Birds
  - Orient using a star as a point source
  - Fly relative to that point
  - Birds will often circle towers with fixed lights
- Insects
  - Dung Beetles
  - Dance on top of ball of dung
  - Difficulty navigating in straight line when views of sky diminished



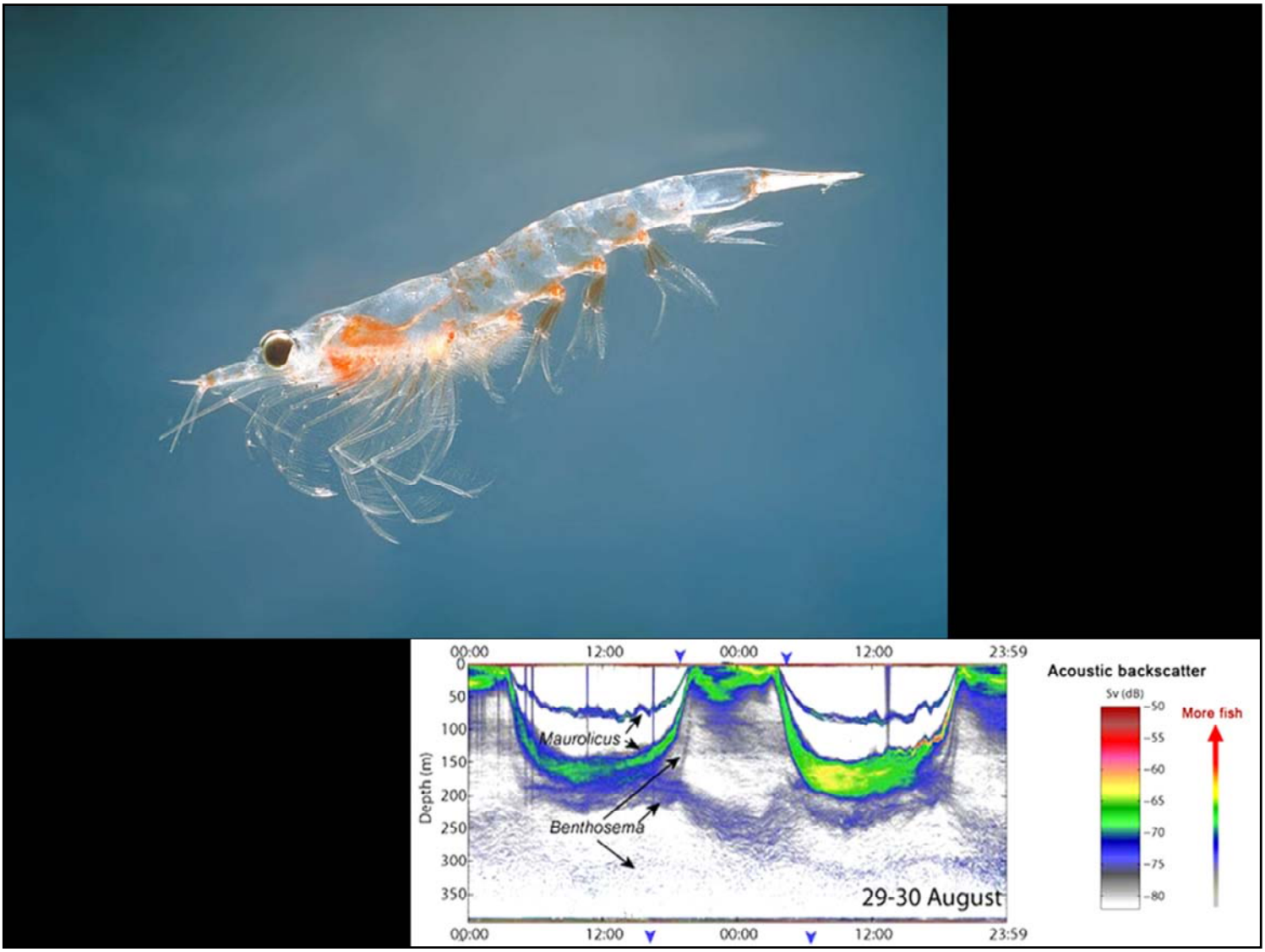
There is a lot of research that demonstrate the effects of stray light on wildlife, however we are still working to better understand the relationships.

The recent study by Van Doren et al (2017) of the 9/11 Tribute in Light in New York City dramatically shows how migrating birds can be disrupted by artificial lighting at night (top figure, see www.pnas.org/cgi/doi/10.1073/pnas.1708574114)

There was a recent study of dung beetles that I felt really illustrated that there is more to learn about the effects of light on insects and other animals. The beetles climb on their dung balls and dance around in circles before rolling the dung ball away from the pile and other beetles. The insects are checking out the sky to get their bearings. They sense the polarization (direction of vibration of light).

Night Skies: Ecological Consequences

- Seals
  - "Harbour seals can steer by the stars", Mauck et al., 2008
  - Learn location of feeding grounds relative to stars



The largest migration on earth happens every night in the oceans as sea creatures large and small swim upward at dusk and downward at dawn. Light can disrupt this migration causing the density of organisms near the surface to decrease at night. The effects of this disruption likely have ecological consequences, but at this point they are not clearly understood.

There are still many unknowns. For example, we know that insects are attracted to light sources. Lights, especially those near natural areas can bring in insects from within a large radius. Unfortunately, the ecological effects of these light traps on insect populations and distributions are still largely unknown.

Night skies is a key component of wilderness character and values. Wilderness quality can be degraded from light that originates hundreds of miles away.

Dark environments are very fragile, and any significant artificial light miles has the potential to overwhelm the natural features of the night sky and the impression of solitude and grandeur.

Even a candle at 1 mile would appear about as bright as the stars in the Big Dipper. It is one of the most common human intrusions that a wilderness user is likely to encounter, decreasing their sense of solitude, and naturalness.

Next, I want to discuss how we measure the photic environment including light from both natural and human sources.

In order to effectively protect and manage a resource you need to be able to measure it. The Natural Sounds and Night Skies Division has an amazing team of scientists and engineers and over the years, NPS has pushed the boundaries in developing technology, methodologies, and protocols for measuring the photic environment.

Natural Light in Sky

Starlight
Galactic
Zodiacal
Airglow

First we'll discuss light from natural sources. In order to assess the effects of anthropogenic light, we must be able to develop a reference condition by measuring the natural light in the night sky. The natural sources of light include Starlight, Galactic light, Zodiacal light, and Airglow.

Starlight - Astronomical Magnitudes

APPARENT BRIGHTNESS OF SOME ASTRONOMICAL OBJECTS

OBJECT	FOOTCANDLES	LUX	V MAGNITUDE
Venus	0.000014	0.00015	-4.4
Jupiter	3.341×10^{-6}	3.67×10^{-5}	-2.9
Sirius	9.14×10^{-7}	9.84×10^{-6}	-1.47
Vega	2.29×10^{-7}	2.47×10^{-6}	0.03
Pleiades	6.50×10^{-8}	7.00×10^{-7}	1.4
Andromeda Galaxy	1.36×10^{-8}	1.46×10^{-7}	3.1
Faintest naked eye stars	3.41×10^{-10}	3.67×10^{-9}	7.1
Faintest naked eye galaxy	4.10×10^{-10}	4.41×10^{-9}	6.9
Faintest stars visible in 8" aperture telescope	2.15×10^{-13}	2.31×10^{-12}	15.1
Faintest objects imaged by CCD in 14" aperture telescope	9.39×10^{-16}	1.01×10^{-14}	21.0
Faintest objects imaged by ground based observatories	1.49×10^{-18}	1.60×10^{-17}	28.0
Faintest objects imaged by Hubble Space Telescope	2.36×10^{-19}	2.54×10^{-18}	30.0

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NPS Night Sky Training

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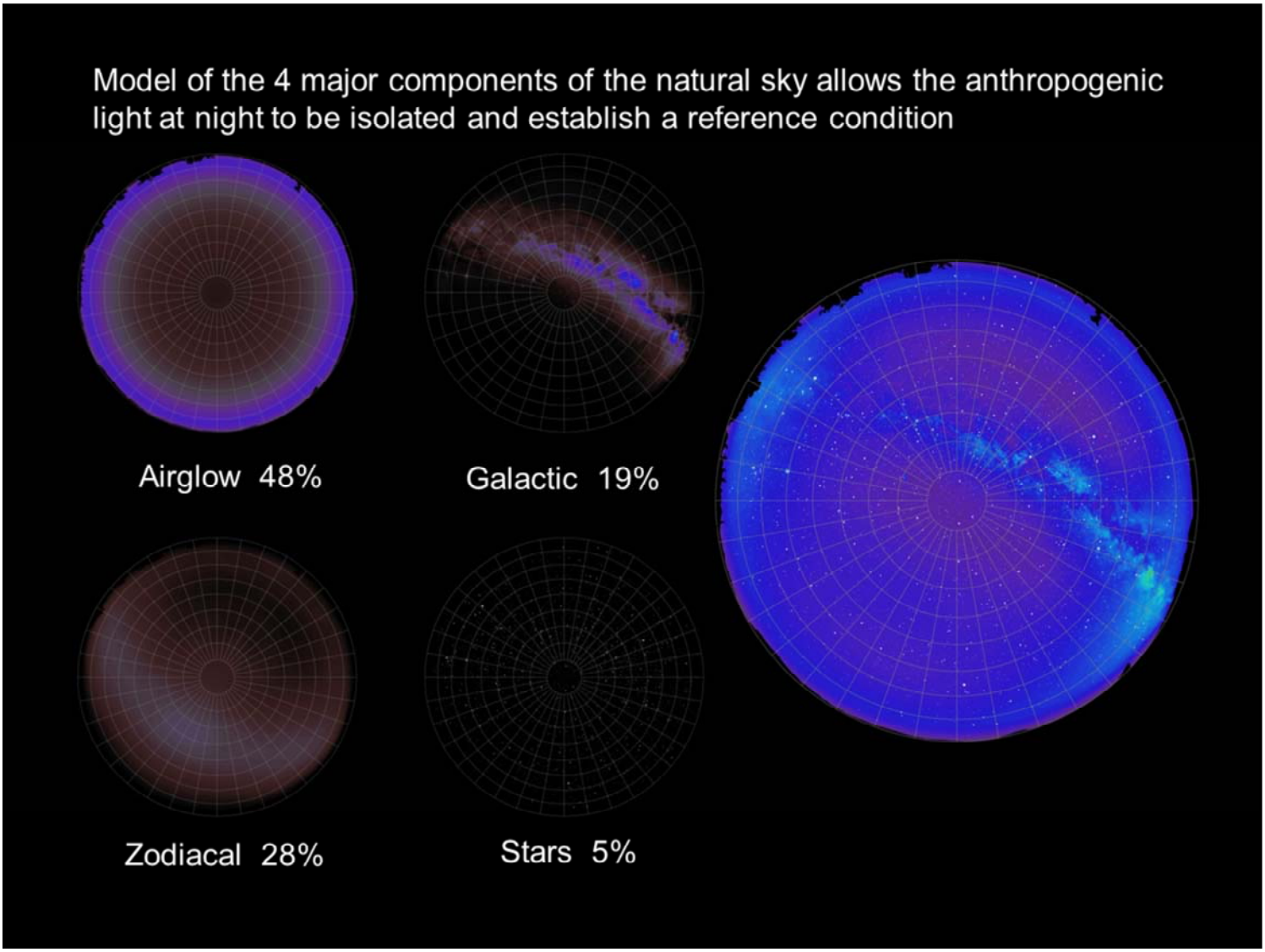
This chart illustrates the brightness of some astronomical objects . As we can see, starlight is not very bright. Venus, the brightest natural object other than the moon, has a illumination level of 0.00015 lux. Compared to other sources of natural light, starlight contributes little to overall light levels.

Galactic light is the accumulated light from milky way. In this image it is the band of light stretching from 1 o clock to 7 o clock.

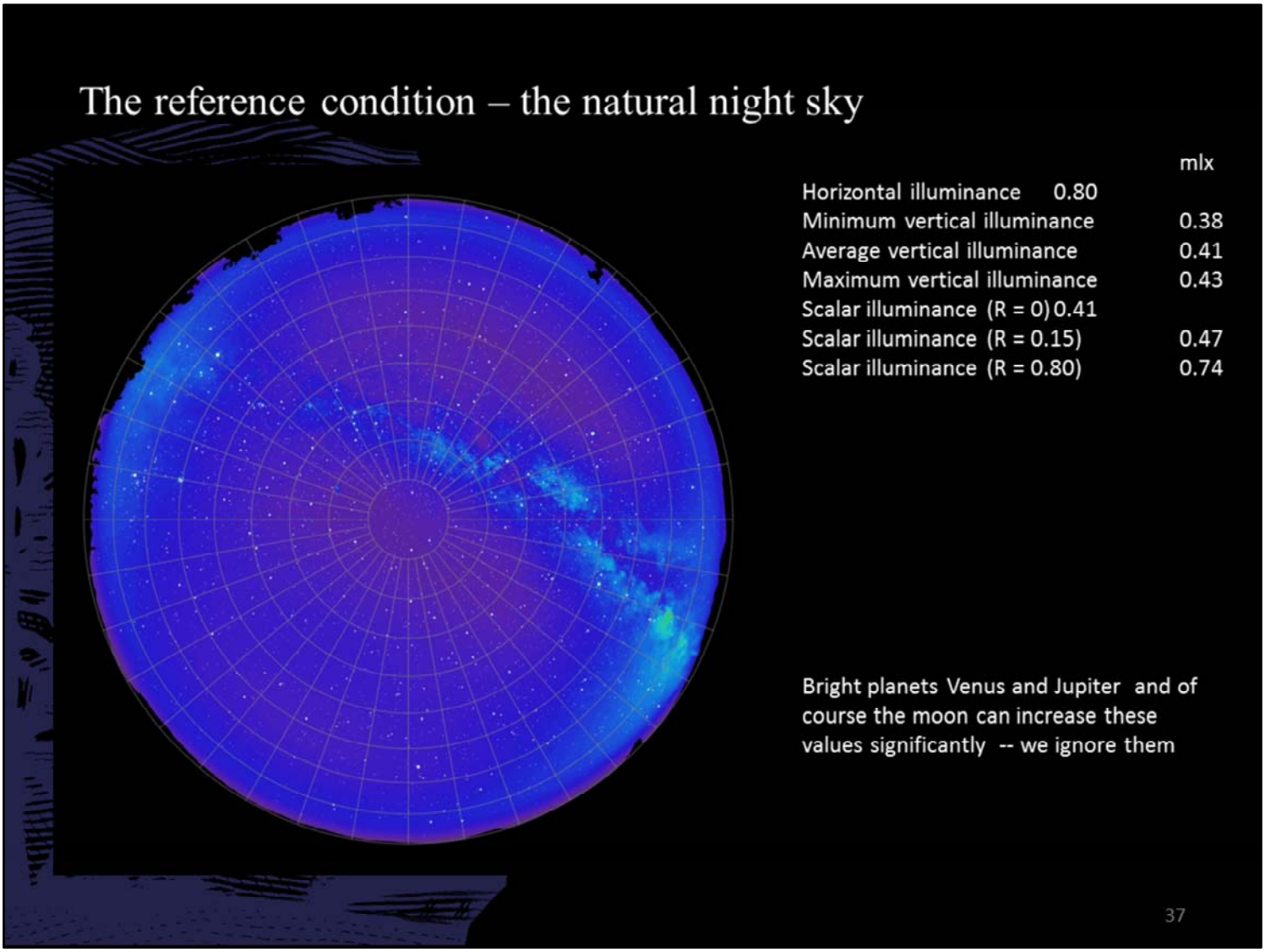
The Zodiacal light, sometimes called “false dawn”. It is sunlight reflected off of dust particles in the planetary plane of our solar system, between Mars and Mercury. Near twilight it forms a wedge-shaped band of light at the horizon in the direction of the sun. It is surprisingly bright under dark clear skies. Zodiacal Light is shown in this image stretching from 3 to 9 o clock.

Airglow is light that emanates from the ionization of gases in the upper atmosphere. In this image you an see the subtle “shell” of light around the earth. The blue-green color is from ionized Oxygen.



Here we have the main components, and the percentage of light that each contributes to the natural night sky. These percentages are averages, all of them vary in brightness.

We can combine these into a model of the natural night sky.



This model of the natural night sky can be used as a benchmark by which we can assess the condition of any night sky. Later in the webinar we will talk about how we use this model to describe existing night sky conditions as a ratio of the natural condition.

Human Sources of Light

Glare

Skyglow

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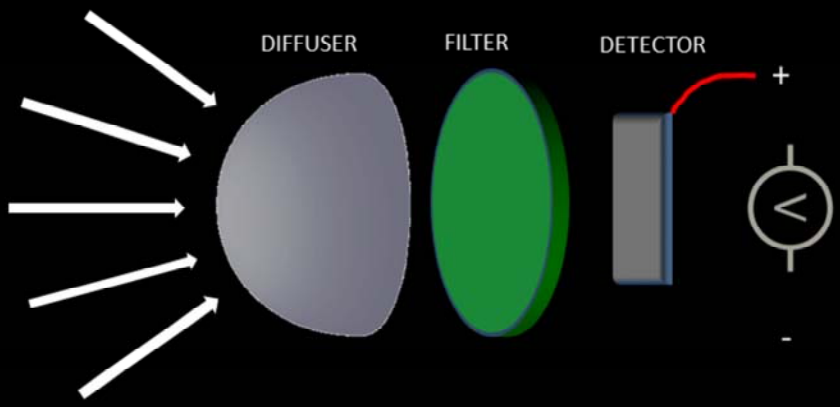
The next topic is the measurement of anthropogenic sources of light. As we mentioned earlier, the two main sources light trespass are glare and sky glow

Measuring Glare



Minolta T10 Illuminance Meter

Primarily used to measure horizontal illuminance at the task area in outdoor lighting. It may be used to measure large amounts of light trespass if held vertically at the property or lighting zone boundary. It is advertised to read linearly in the range 10 mlux to 299,000 lux

To measure glare, you can use an off the shelf illuminance meter. Less than $1000. Some illuminance meters include spectrometers.

Measuring Skyglow

Unihedron Sky Quality Meter

Designed to measure night sky brightness near the zenith. Calibrated at the factory to read out in logarithmic (magnitude/arc sec^2) luminance units approximating the visual band.

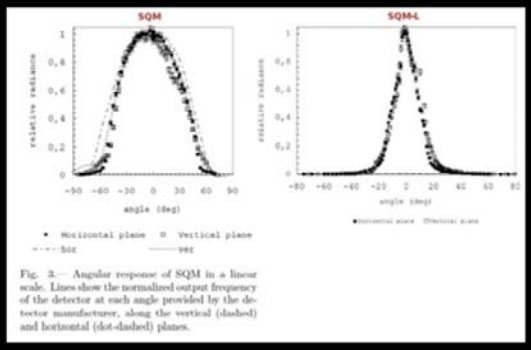


Fig. 3.— Angular response of SQM in a linear scale. Lines show the normalized output frequency of the detector at each angle provided by the detector manufacturer, along the vertical (dashed) and horizontal (dot-dashed) planes.

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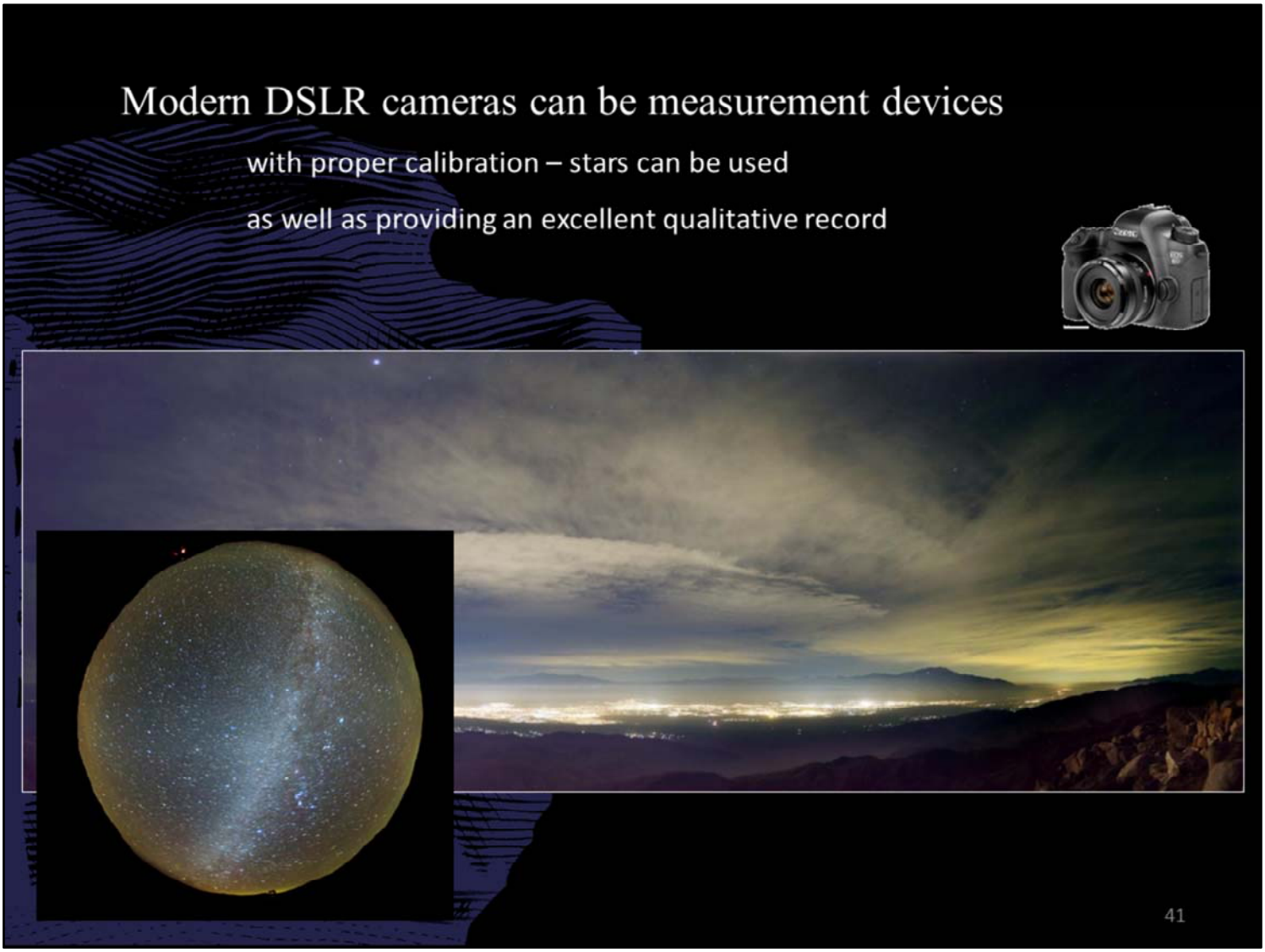
For sky glow, a sky quality meter can be used. Under $200 Measures sky brightness near the zenith.

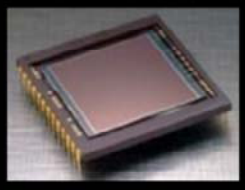


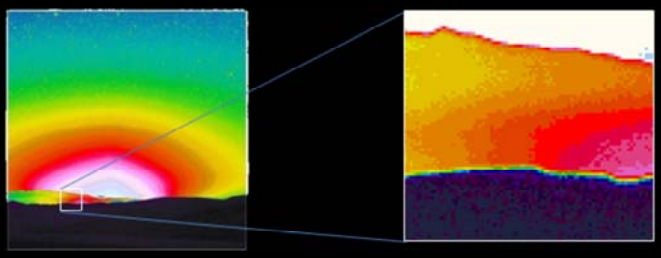
Our team is currently working on developing technology, methodologies and protocols for using DSLR cameras to measure light levels.

The Charge-Coupled Device (CCD)

Since the 1980s, the charge-coupled device has been the preferred detector for accurate photometry at low light levels.

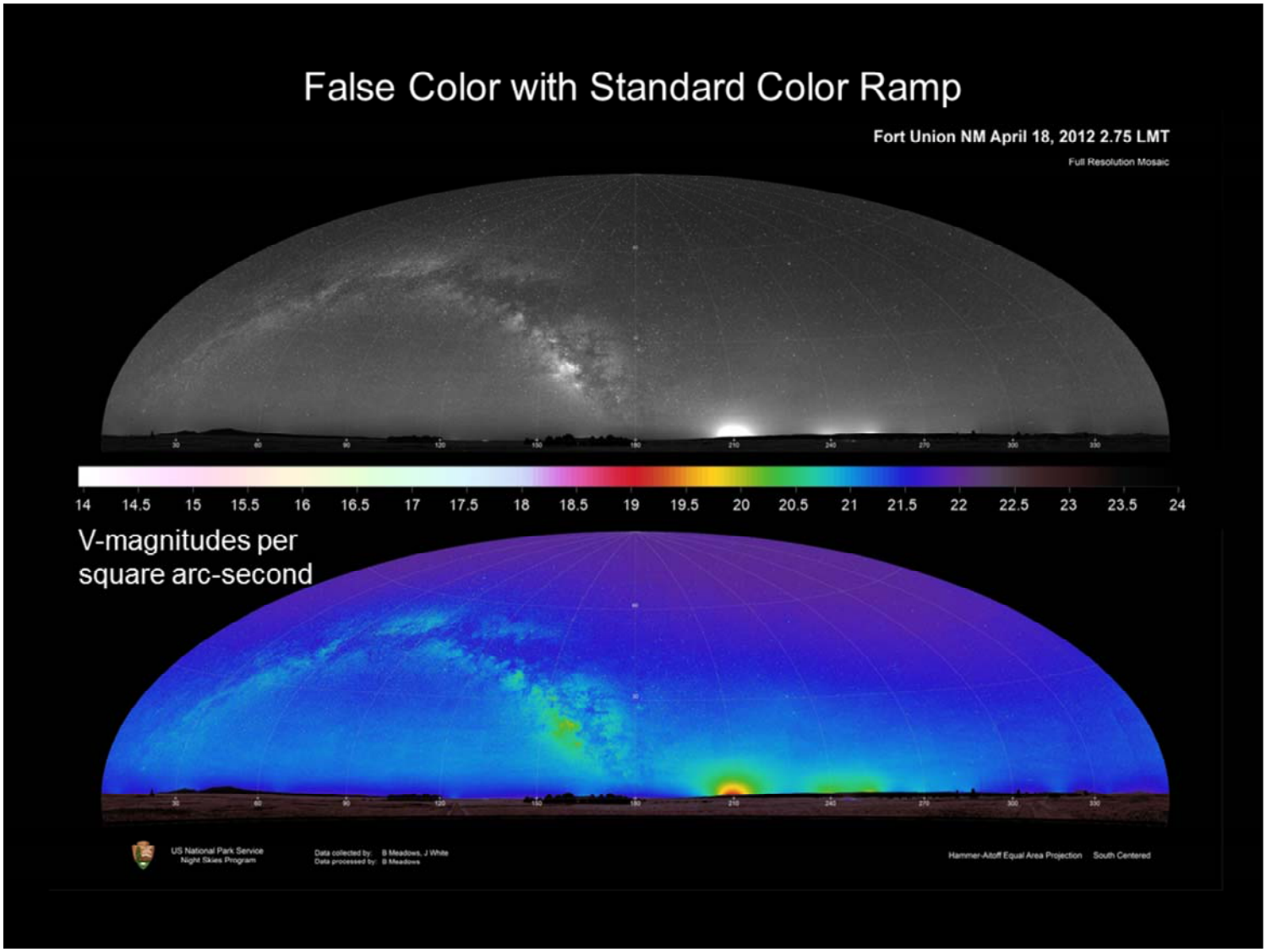
A CCD Array is essentially a matrix of photodiodes, with associated extra layers of semiconductors to capture, store, and transfer the electrons produced by each pixel's exposure to light. An array is a digital image, and data from each pixel can be displayed either in grayscale or false color to show pixel-to-pixel variations in light intensity over the full frame of the CCD.



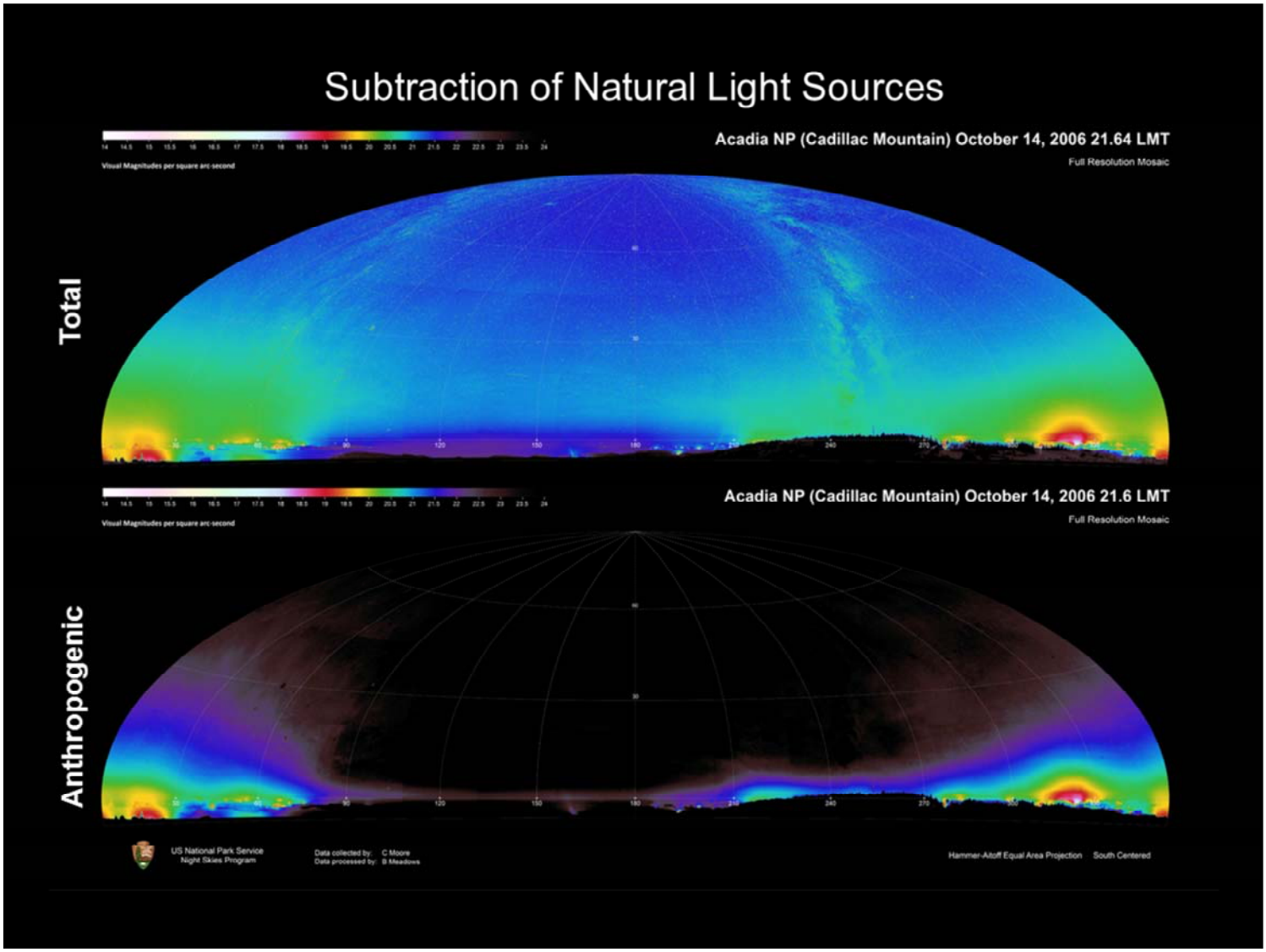


This is the method that NPS uses to assess night sky quality

By creating a mosaic of 45 images, NPS can assess the entire night sky and show an astonishing level of detail



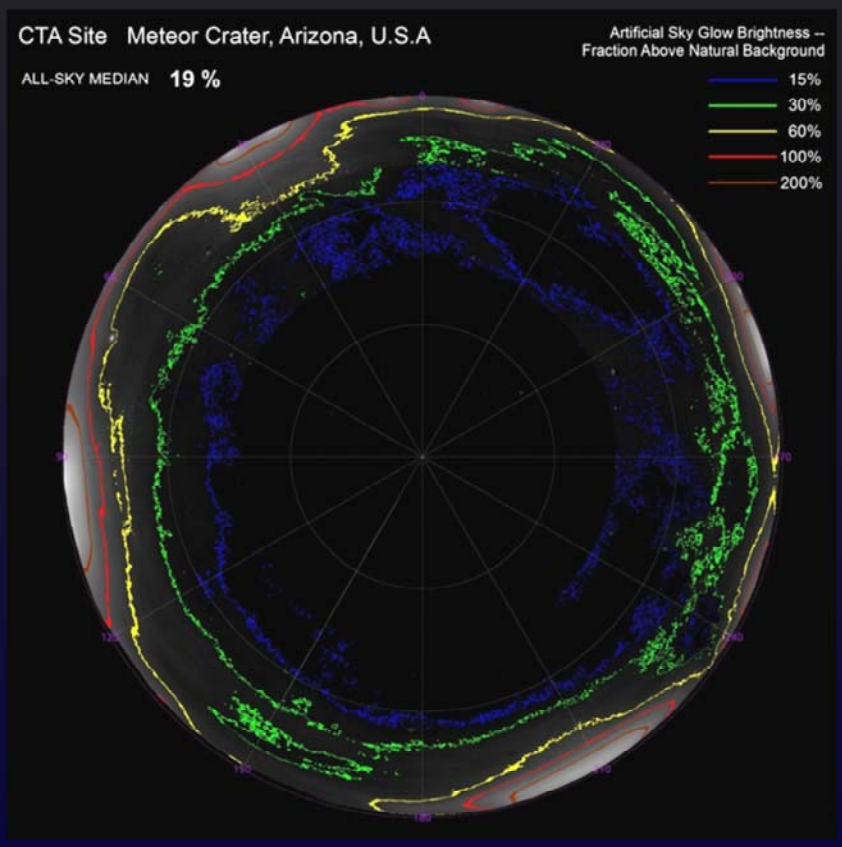
We can present that data in natural and false color graphics to better demonstrate variations in light levels.



We measure the total light and subtract the natural sources from the benchmark we developed and that gives us the portion of the light that is from anthropogenic sources.

We can compare the anthropogenic data to our natural sky benchmark to calculate the Anthropogenic Light Ratio

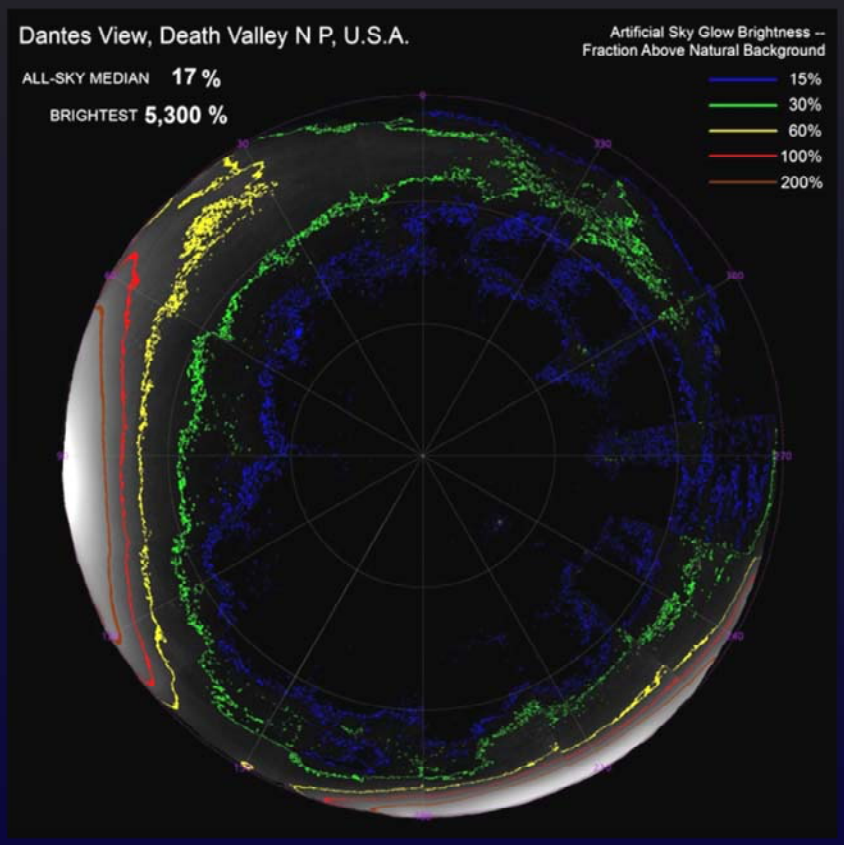
Meteor Crater, Arizona



Here we have created contours illustrating various levels of the ALR. For example, the brightest areas within the brown contours are 200% brighter than natural conditions. The yellow contours represent the areas that are 60% greater than natural, and areas within the blue contours are 15% brighter than natural conditions.

The median level for the entire sky is 19% above natural.

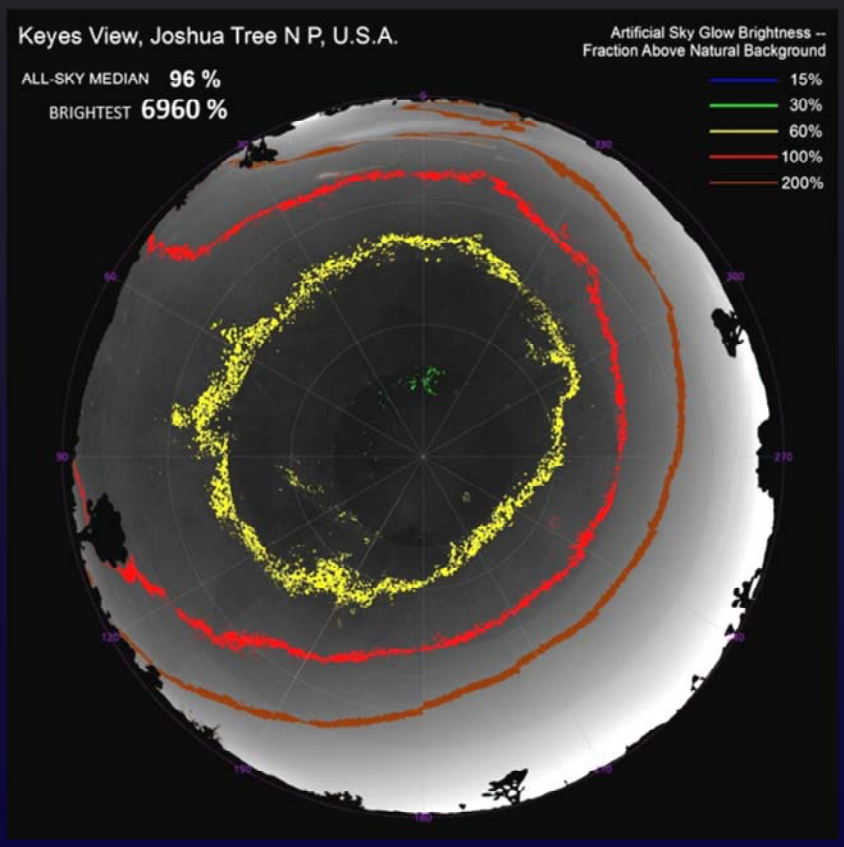
Death Valley National Park, California, U.S.A.



This is a point in DEVA called Dante's View. It's at a higher elevation less terrain shielding. That's Las Vegas on Left at 9 o'clock and las Angeles on Right at 5 o'clock.

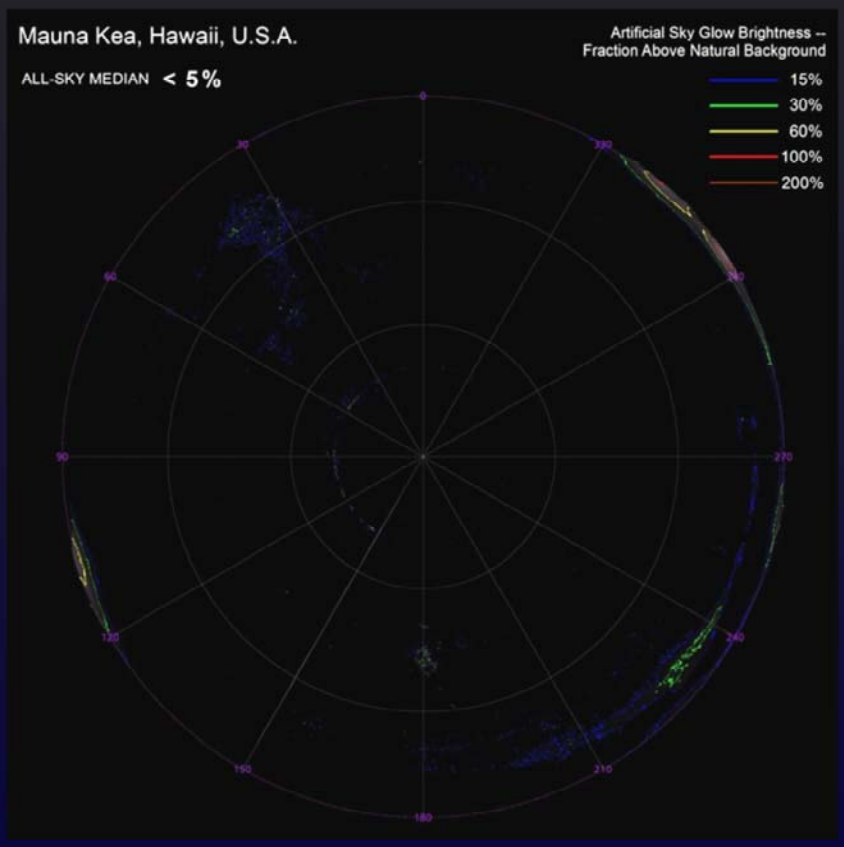
Here the all sky median is 17% and the brightest areas are 5,300% brighter than natural.

Joshua Tree National Park, California, U.S.A.

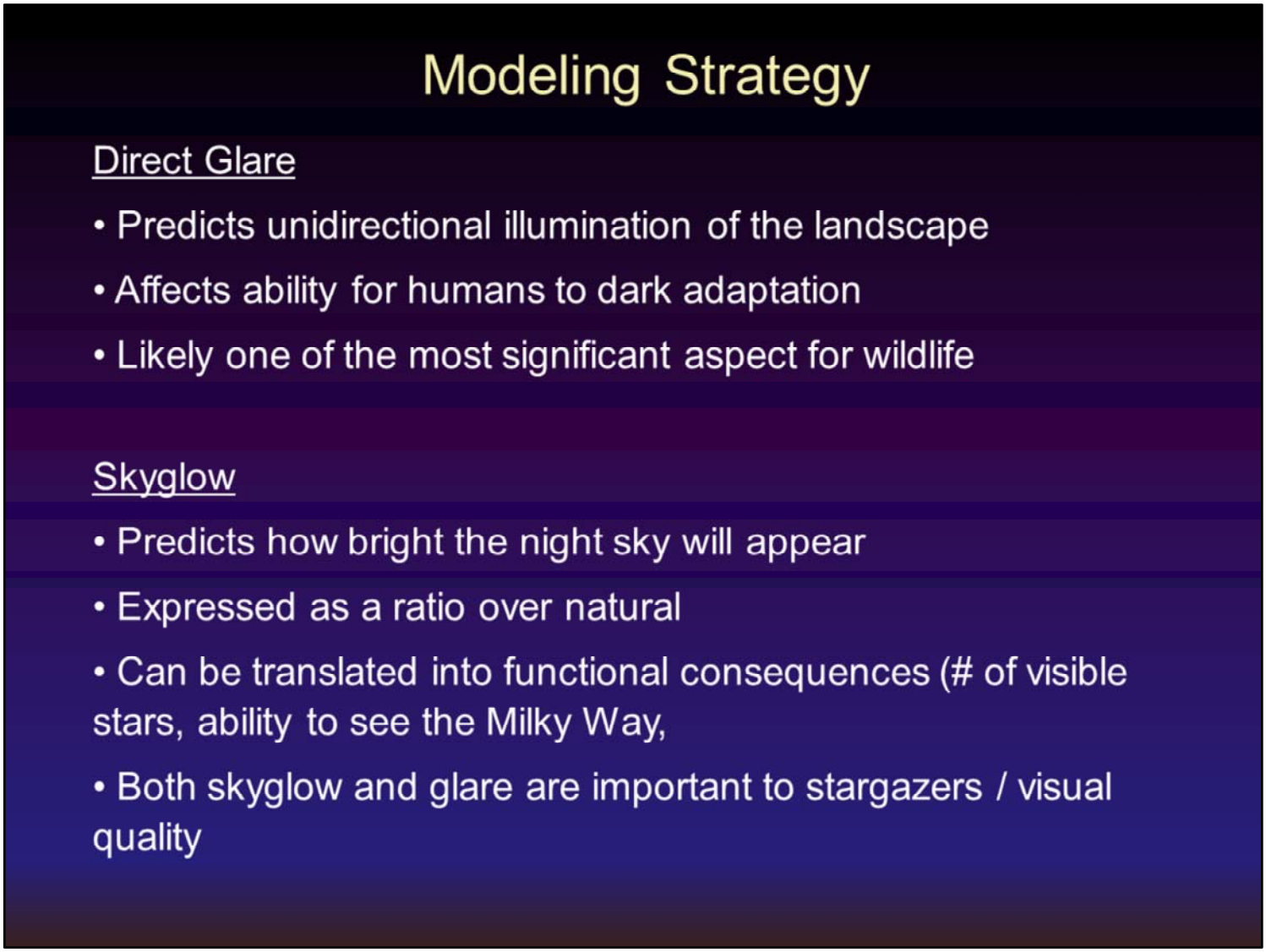


This is from Keye's view in Joshua Tree, a popular lookout with sweeping views. It overlooks the Coachella Valley and Palm Springs. As a result, the ASM is 96% above natural and the brightest area is almost 7000% above natural.

Mauna Kea,
Hawaii, U.S.A.



This image demonstrates the ALR contours for Mauna Kea. The sky there is nearly pristine and the all-sky median is less than 5%. Exceeds our measurement threshold.



We can also use models to determine predicted levels of light from proposed actions.

For both glare and skyglow modeling:
- Possible to test different mitigation measures
- Possible to test effects of alternative lighting strategies
- Can be verified by monitoring

Glare modeling is fairly straight forward. Go to slide.

Sky glow modeling …predicts (go to slide)

Glare Modeling Input

- Established methods for measuring glare
- Geographic locations of light sources
- Key observation point of interest
- Atmospheric conditions
- Lighting (Lumens/Brightness, Direction/Aim)

Simplest of models — uses the Inverse Square Law and spreadsheet to calculate vertical illuminance at a given distance

Glare modeling is fairly straight forward and can be completed in a spreadsheet using the Inverse square law. Inputs for this kind of modeling include (Go to slide)

Skyglow Modeling Input

- Geographic locations of light sources
- Key observation point of interest
- Atmospheric conditions
- Lighting (Lumens/Brightness, Direction/Aim, Color)

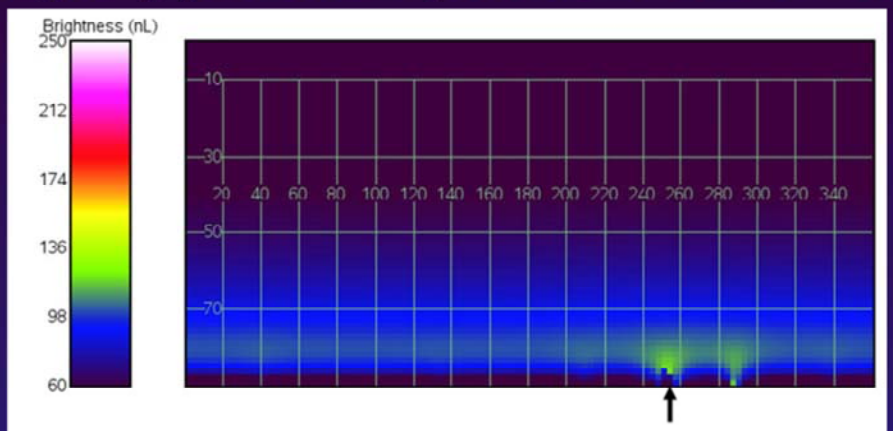
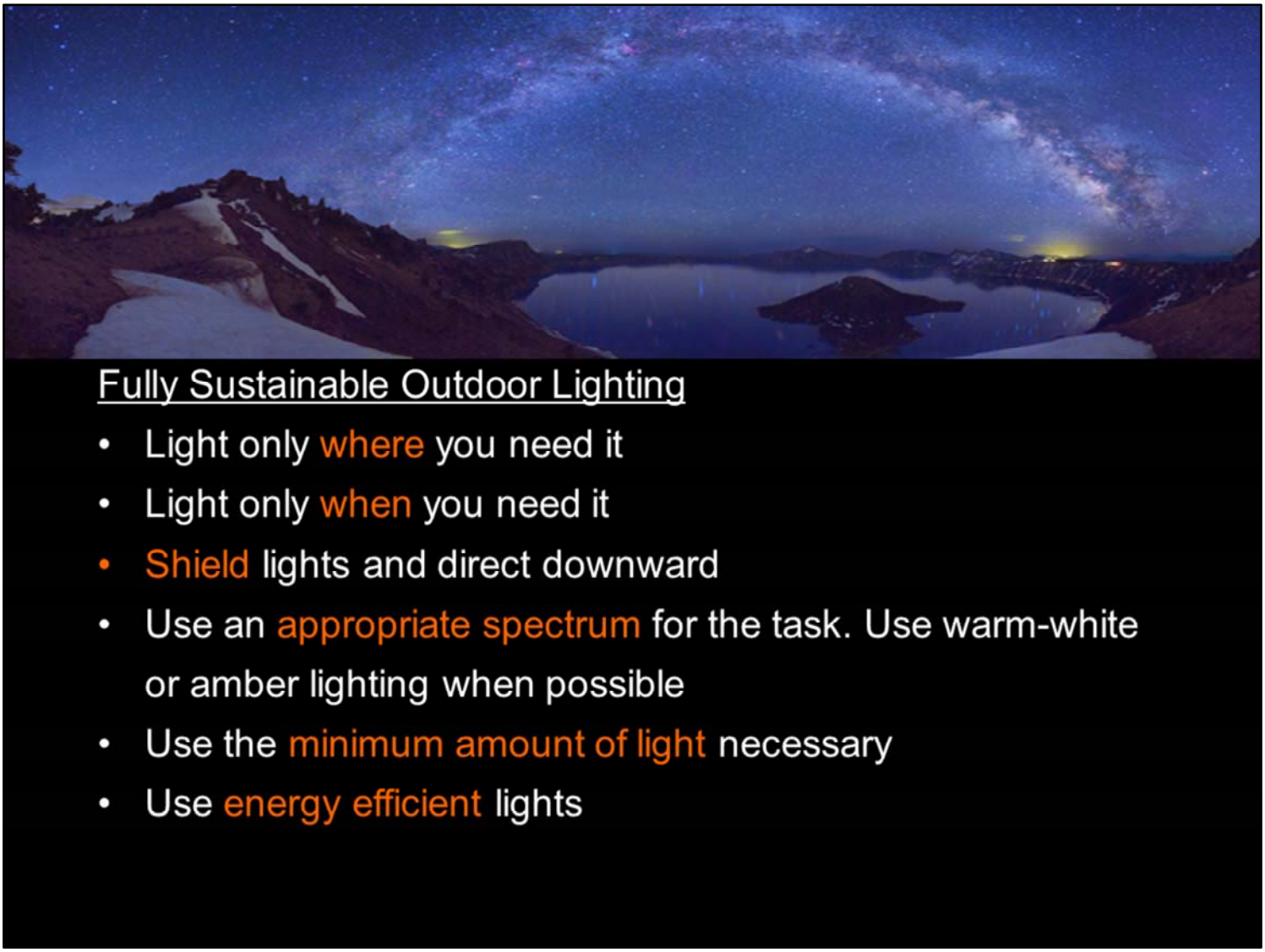


Figure 7. As Figure 5, with *brightest* lighting at the Alton tract.

- NSNSD is working on a method to model sky glow from satellite data

Skyglow modeling is a more complex and requires some pretty sophisticated models. It really represents some cutting edge science, but there are several consultants who can conduct this type of analysis. The inputs are similar to glare modeling.

Sustainable Outdoor Lighting



Six Principles of Sustainable Outdoor Lighting

Light only where you need it

Not all areas need to be lit

In some cases overlighting can make wayfinding less safe by destroying scotopic vision

Transition zones between Lit and unlit areas

Encourage use of headlamps And flashlights when needed

Source: bayphotos.blogspot.com

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Legacy lighting. Is it necessary?

Light only when you need it

Use Lighting Controls Effectively

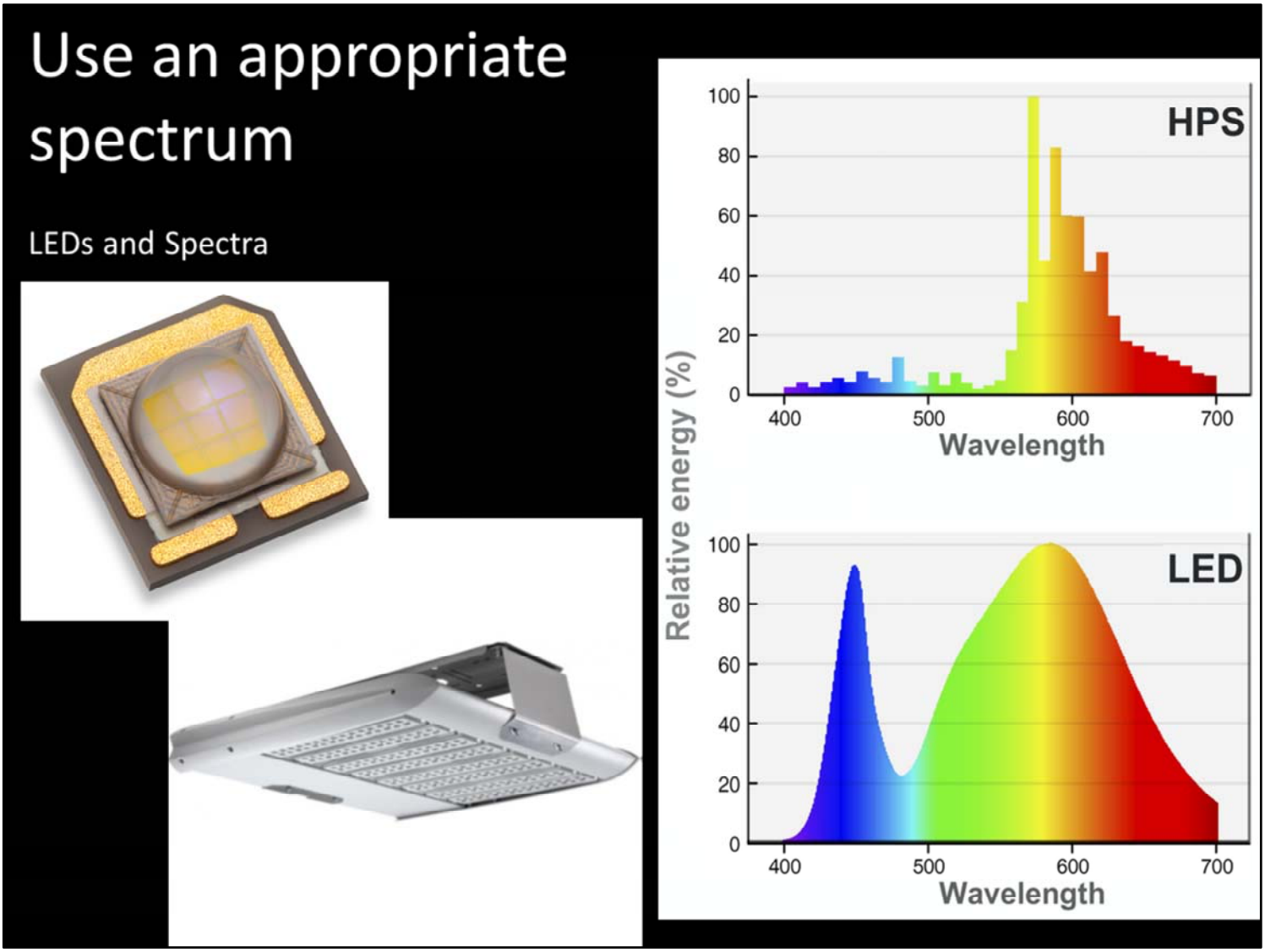
Motion Sensors
Photo Sensors
Timers
Dimmers
Changeable CCT

NPS Night Sky Training

D Duriscoe April 2011

Shield lights and direct downward

Full cutoff fixtures. Terrain shielding.

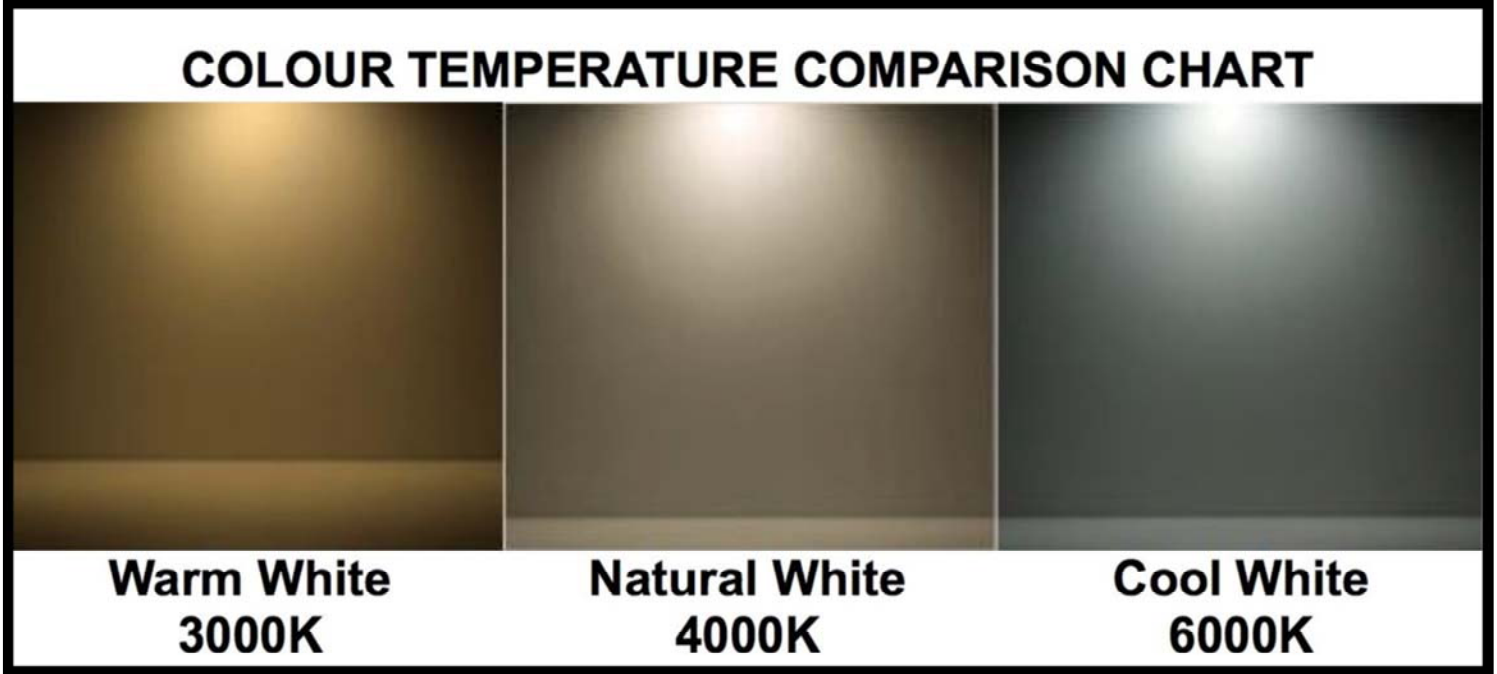


The next principle is to Use the Appropriate Spectra for the task.

All lights have a spectrum. LEDs have a blue spike.

Phosphors (yellow coating) makes the bluish light appear warmer (lower CCT).
In the past, phosphors decreased the efficiency of the light (lumens/watt). That's why early LED lighting was often perceived as harsh and "blue". Lights included less phosphor resulting in higher CCT in order to maximize energy efficiency. less Newer technologies have reduced that effect so the reduction is negligible. Many cities and towns that initially installed 5000k LEDs are replacing them with 3000K bulbs.

Avoid Blue Tinted Light



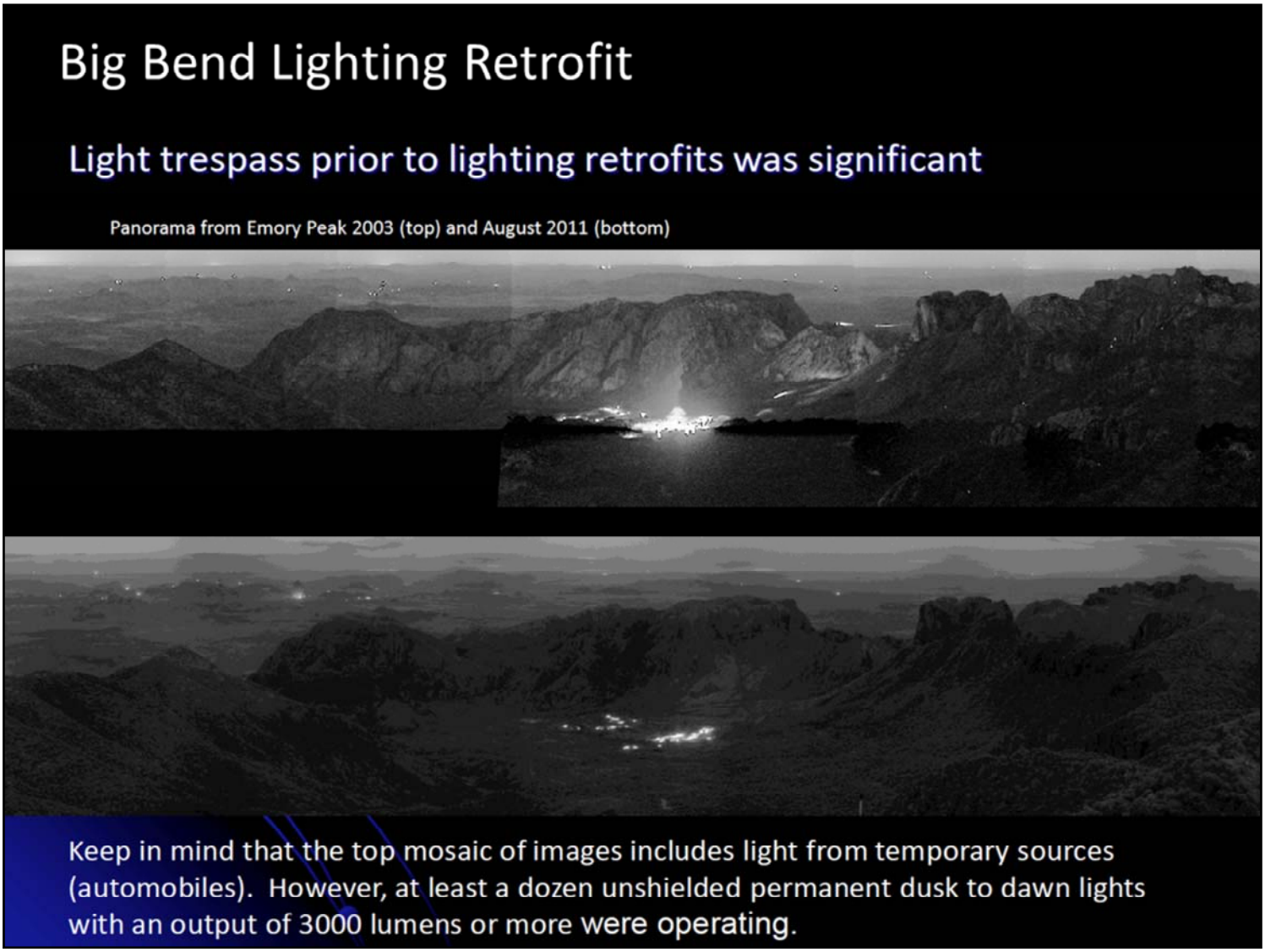
This slide illustrates different CCT levels.

In terms of spectra, in general it's best to avoid blue tinted (higher CCT) lights. The blue component of the spectrum doesn't add much to our vision, but disturbs has greater health and ecological effects.

American Medical association recommends 3000K or lower

In addition to the effects on circadian rhythm, Lights with a lot of energy in the blue end of the spectrum (such as metal halide and white LEDs) are scattered more by the atmosphere and cause more skyglow.

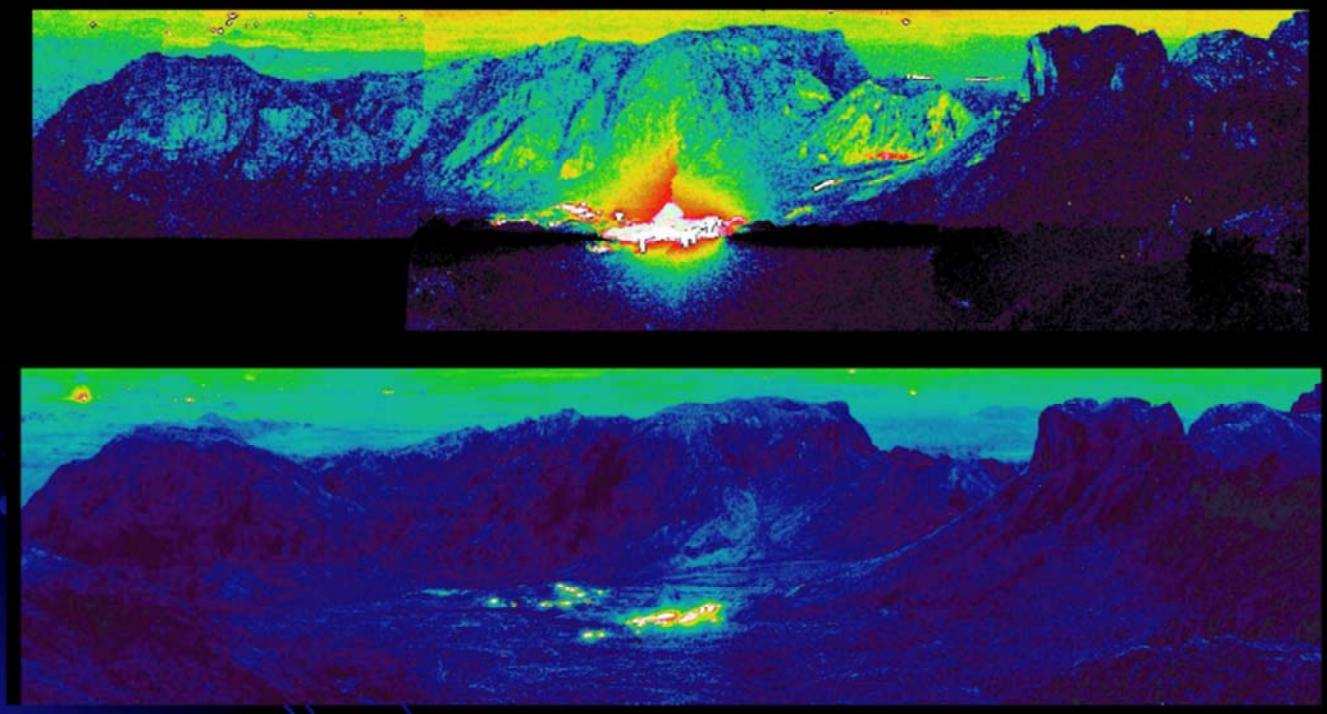
Minimize the amount of light you use. Examples of two visitor centers. White façade lighting vs muted fixtures mounted under canopy. Use of low intensity bollards instead of overhead lights on stairs. That light is enhanced by painted stairs to increase visibility. Reflective surfaces. Increase contrast. This way you can maintain safety with less light.



The results seen from atop Emory Peak in Big Bend speak for themselves.

Light trespass prior to lighting retrofits was significant

Panorama from Emory Peak 2003 (top) and August 2011 (bottom)



False color enhances dynamic range, two different cameras are not calibrated exactly to each other, but approximately so. 2003 a clearer night, distant landscape brighter.

... and in false color showing the significant improvement.

Thank
You